Properties of Ferrofluids Resulting in the Lifting of Rare Earth Magnets

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Introduction

Ferrofluids were first created by NASA in the 1960's to move fuel in a spacecraft without assistance from gravity [1]. Since then, a variety of uses for ferrofluids have been found. By investigating the structure-property relationship between the amount of ferrofluid, structure, and the force needed, property, to get the magnet surrounded in that fluid to contact the table, new real world applications can be found, and current ones can be explained. The scope of this project will include the use of iron oxide ferrofluid and neodymium rare earth magnets. A clear procedure and direct measurement of force will be used. It is expected that when ferrofluid is added to the surface of a magnet, the fluid will collect evenly around the magnet and lift it off the surface it is on. It is also hypothesised that as more ferrofluid is added to the magnet, the system should resist a greater force, until ferrofluid can no longer collects on the magnet's surface due to gravity being stronger than the magnetic field. This should result in a sigmoidal distribution [Appendix B].

Methods

When gathering materials, some were bought and some were used from the lab. First, ferrofluids and magnets were bought from Amazon as to not ruin the magnets and limited amount of ferrofluid in the lab [2][3]. Next, a Vernier Force Meter was borrowed from the physics lab. Then two petri dishes, a pipet, gloves, styrofoam cup, tape and paper towel were taken from the chemistry lab materials. A three decimal place analytical balance and logger pro software on a LabQuest were also used.

The clean petri dish and magnet masses were found. Next, a piece of styrofoam was taped around the force sensor's probe to protect it from the ferrofluid. The force sensor was connected to the LabQuest and calibrated to zero Newtons. Ferrofluid was pipetted onto the magnet until the the magnet could be noticeably depressed before making contact with the table. Then, the force sensor was used to detect how many Newtons of force it took to touch the table. This was difficult because ferrofluid is opaque and one could not see when the magnet touched the table. Therefore, one had to feel when the table was contacted; along with using the graphing function on the LabQuest to detect the amount of force the ferrofluid could resist. The value found was averaged across three repeated measurements. The whole petri dish, magnet, ferrofluid combinations mass was found. This procedure was repeated two more times with greater amount of ferrofluid, resulting in three recorded, averaged values of force (N) for each trial [Table 1, 2 ; Appendix A]. Finally, the pipet was used to skim off ferrofluid from the magnet before everything was cleaned.

Results and Calculations

Seen below in Table 1 is the experimental masses taken in the experiment. The calculated volume of ferrofluid based on the density is also shown. The density of the ferrofluid was found in research to be 1.315 g/ml [4].

Table 1 : Massed Measurements					
Trial	Clean Petri Dish Mass (g)	Clean Magnet Mass (g)	System Mass (g)	Mass of Ferrofluid (g)	Volume of Ferrofluid (ml)
1	12.290	19.300	43.996	12.406	9.434
2	12.290	19.300	51.313	19.723	15.00
3	12.290	19.300	56.268	24.678	18.77

Calculated Mass of Ferrofluid

Mass of Ferrofluid = System Mass - (Clean Petri Dish Mass + Clean Magnet Mass)

Trial 1: 12.406g = 43.996g - (12.290g + 19.300g)

Calculated Volume of Ferrofluid

Volume of Ferrofluid = Mass of Ferrofluid / Density of Ferrofluid

Trial 1: 9.434 ml = 12.406g / (1.315 g/ml)

Seen below in Table 2 is the experimentally measured force value (in Newtons) found to flatten the magnet to the table. Also included is the average for each trial, or different amount of ferrofluid.

Table 2 : Force Measurements			
	Trial 1	Trial 2	Trial 3
Force 1 (N)	2.139	5.201	5.983
Force 2 (N)	2.870	4.933	6.025
Force 3 (N)	2.114	4.756	5.659
Averaged Force (N)	2.374	4.963	5.889

Calculated Average Force Resisted by Ferrofluid

$$\text{Average Force} = \tfrac{1}{3}(\text{Force 1} + \text{Force 2} + \text{Force 3})$$

Trial 1: $2.374 = \tfrac{1}{3}(2.139 + 2.870 + 2.114)$

By using the average force and calculated mass of ferrofluid, a graph was made. The transitional and plateau phase of the expected sigmoidal distribution is present on the graph.

Plotted Graph of Volume of Ferrofluid vs Force

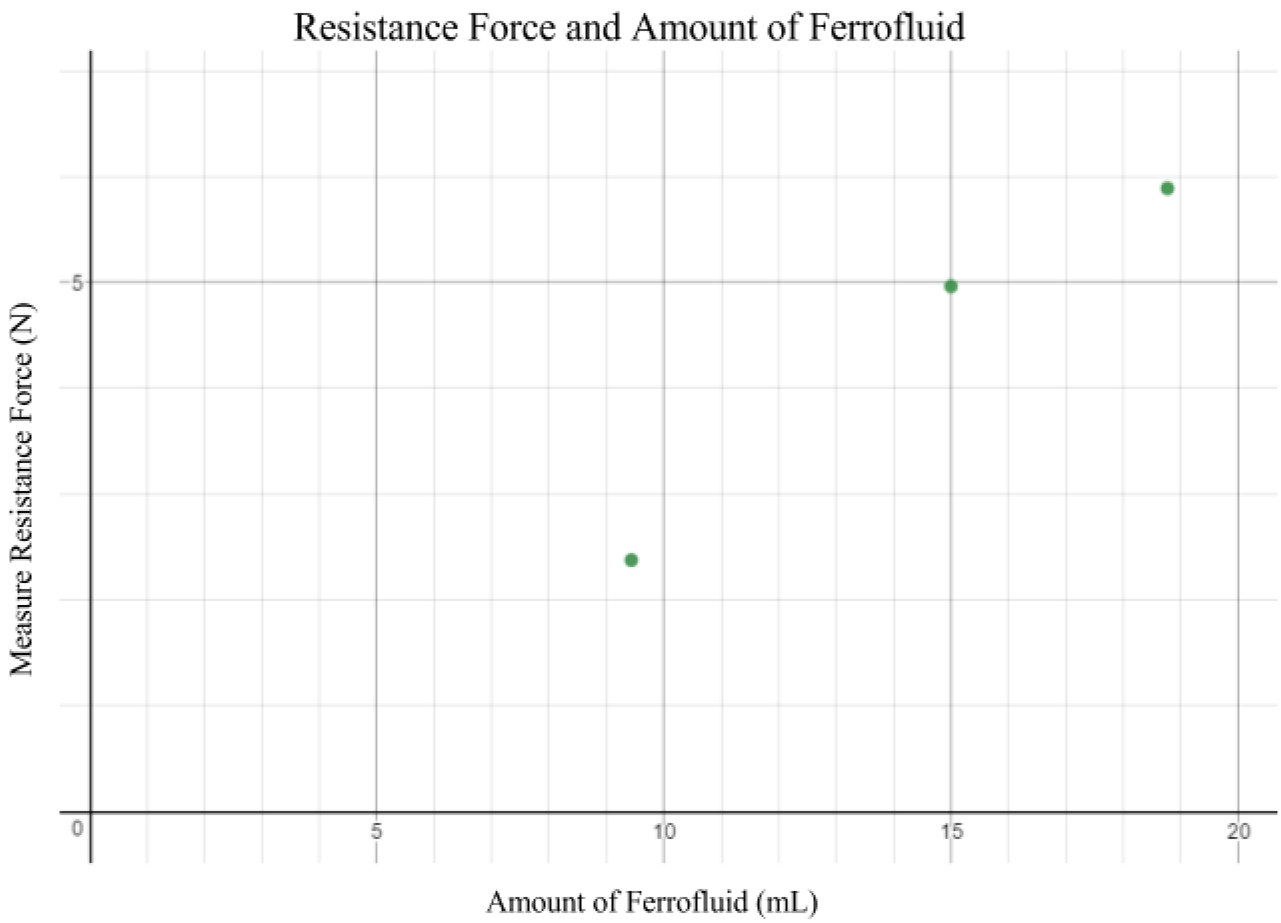


Figure 1:Graph of resistance force and ferrofluid volume

Discussion

A clear structure-property relationship between amount of force resisted by the ferrofluid and the amount of ferrofluid can be found from our data. As ferrofluid collected around the magnet it was observed that the ferrofluid was pulled to the magnetic pole under the magnet, and caused a force that pushed the magnet up [Appendix A]. An equilibrium was reached when this force counterbalanced the force from gravity of the magnet. This procedure aimed to find the magnetic force by measuring the resistance force required to push the magnet to the table.

Assuming the resistance force and the applied force are Newton's Third Law pairs, the forces should be equal in magnitude but opposite in direction. The amount of fluid and magnitude of resistive force relationship is important to establish, as it is the basis of the structure-property correlation being tested and discussed in this report. As shown in Figure 1, the three points, gathered from the experiment, of the graph indicate a sigmoidal distribution in the relationship between this magnetic force and volume of ferrofluid [Appendix B].

This experiment highlights an important property of ferrofluid but was not rigorously conducted and therefore has sources of error and places to improve the procedure. First, a better procedure for measuring the magnetic force should be found. By not always knowing exactly when the magnet touched the table, some tests had to be re-done and the data used still has uncertainty. Second, directly related to this procedure, ferrofluid is difficult to contain and mass measurements included ferrofluid not directly on the magnet or involved in the observed magnetic force. This introduces error in the calculated weight of ferrofluid used in each trial as the mass measurements should be less than calculated because some of the ferrofluid that was thought to be on the magnet due to mass was actually on the petri dish. The mass should have been less for any given force resisted. These errors may be corrected in future experiments with ferrofluids.

The methods used in this report may be further improved upon and leave more unanswered questions for which further experimentation is needed. First, more data points to fill out the graph should be found to solidify the tentative relationship we have found between the force from the ferrofluid and quantity of ferrofluid on the magnet. Second, further research may be done to find if a relationship between the strength of the magnetic field and force from the ferrofluid exists. Further research may also investigate how ferrofluids react when levitated in space, then a known mass is applied on top of the system. All of the properties found in these possible experiments can give insight into other properties and applications ferrofluids have.

The resulting property that is shown in this report is that ferrofluid can supply a variable force off the surface of a magnet. This property has real world applications in small electronics where a variable lifting force is needed. Ferrofluids are used in motors or speakers where the ferrofluid can dampen unwanted vibrations. As seen in Figure 2, ferrofluid will lift up the axis of a speaker and allows the closed system to vibrate without harming the overall structure. Ferrofluid may also be used for dynamic sealing. This is useful when a seal is needed between two containers that move together. The ferrofluid is able to track the container and change the force applied, keeping two environments separated. With further study more uses for ferrofluid may also be found. [5]

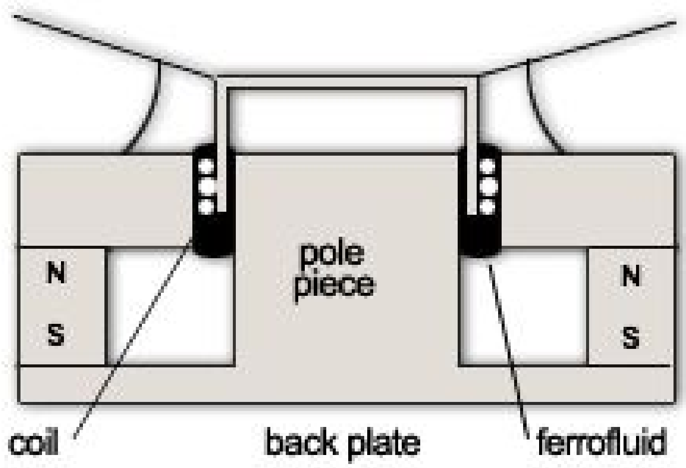


Figure 2: Ferrofluid in audio speaker [6]

Conclusion

The motivation of this project was to demonstrate the existence of a unique structure property relationship of ferrofluids. This report investigated the relationship between the volume of ferrofluid as a structure and the magnetic force pushing on a magnet as a property of this structure. It was observed how when more ferrofluid was added to a magnet, the resistance force holding the magnet off the table increased. This structure-property relationship may be applied in the world to dampen vibrations, such as in motors, to increase efficiency. This report is limited by the uncertainties in the measured force. The procedure could be further altered to directly test the force pushing up on the magnet and find more data points for the sigmoidal distribution. Other tests may include how the strength of the magnet is related to the magnetic lifting force and if ferrofluid suspended in a magnetic field can hold a mass.

References

[1] "Magnetic Fluids Deliver Better Speaker Sound Quality", *Spinoff.nasa.gov*, 2017. [Online]. Available: https://spinoff.nasa.gov/Spinoff2015/cg_2.html. [Accessed: 24- Apr- 2017].

[2]"Amazon.com: Ferrotec Magnetic Ferrofluid -2oz- 60ML Bottle, Great for Science Projects: Toys & Games", *Amazon.com*, 2017. [Online]. Available: https://www.amazon.com/gp/product/B00126P1NW/ref=od_aui_detailpages00?ie=UTF8&psc=1 [Accessed: 9- Apr- 2017].

[3]"6 Piece N52 1.26" x 1/8" Most Powerful Disc Neodymium Magnets CMS Magnetics: Amazon.com: Industrial & Scientific", *Amazon.com*, 2017. [Online]. Available: https://www.amazon.com/gp/product/B01I1ZB2SE/ref=od_aui_detailpages00?ie=UTF8&psc=1. [Accessed: 9- Apr- 2017].

[4] FerroTec, "Safety Data Sheet: EFH Series Ferrofluid", FerroTec, Bedford, 2014.

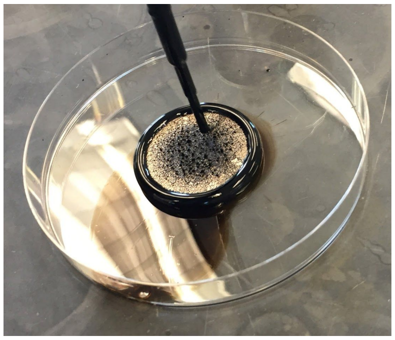
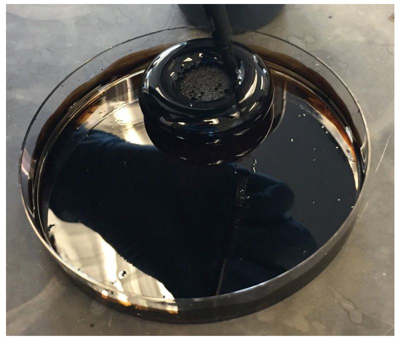
[5] C. Scherer and A. Figueiredo Neto, "Ferrofluids: properties and applications", *Brazilian Journal of Physics*, vol. 35, no. 3, pp. 718-727, 2005.

[6] "Role of a Ferrofluid in a Loudspeaker System", *Liquidsresearch.com*, 2017. [Online]. Available: http://www.liquidsresearch.com/en-GB/for_loudspeaker_applications-53.aspx.

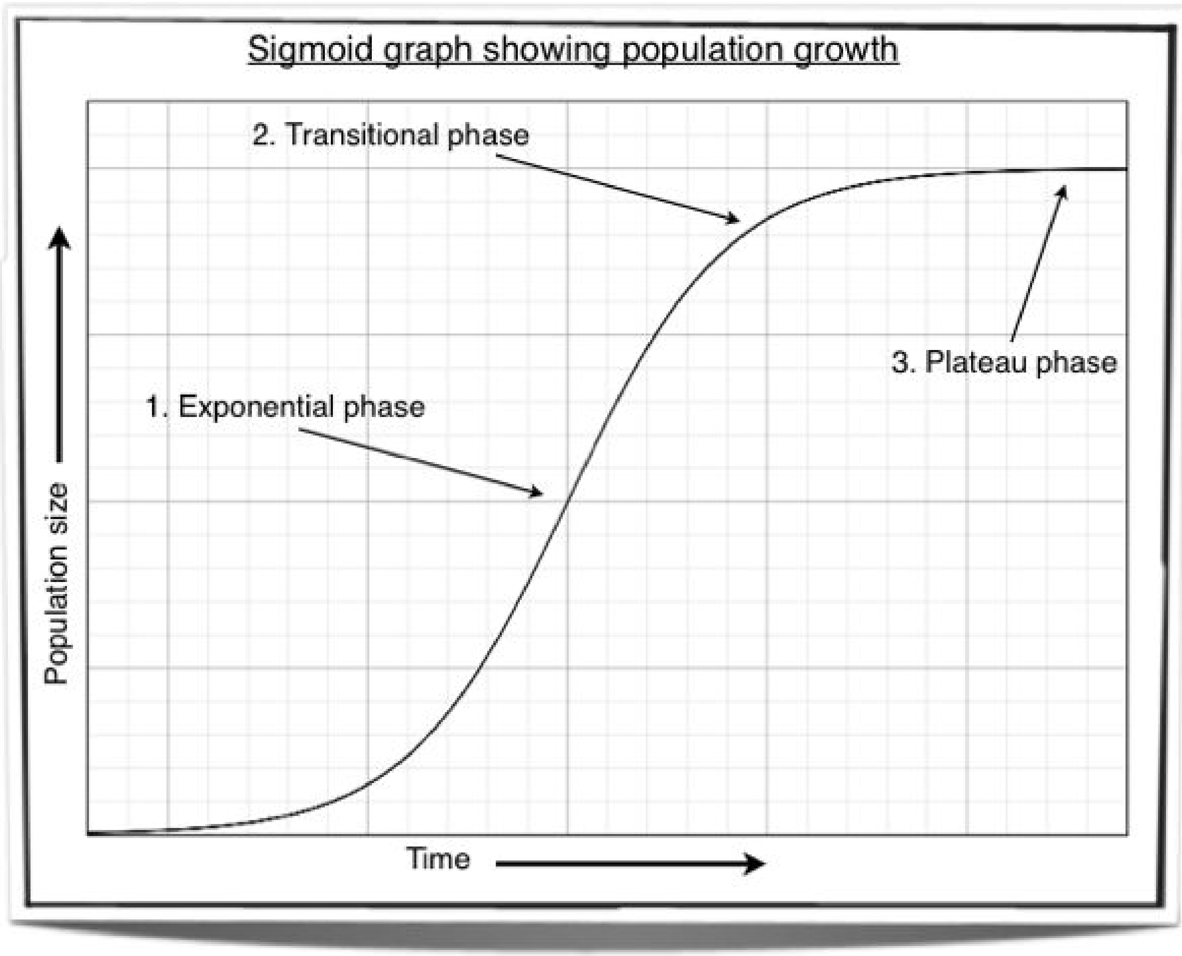
[Appendix B] "IB Biology Notes - 5.3 Populations", *Ibguides.com*, 2017. [Online]. Available: http://ibguides.com/biology/notes/populations. [Accessed: 02- May- 2017].

Appendices

Appendix A

Trial 1:	Trial 2:	Trial 3:
		

Appendix B


Sigmoid graph showing population growth
2. Transitional phase
1. Exponential phase
3. Plateau phase
Population size
Time